Patent Application of

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For

TITLE: SUPER WHITE CHOLESTERIC DISPLAY EMPLOYING BACKSIDE CIRCULAR POLARIZER

FIELD OF INVENTION

The present invention relates to cholesteric displays, more specifically, to reflective cholesteric displays employing a backside circular polarizer. In the paper white mode, the bright white state is achieved in display's focal conic texture area; and the dark color state is obtained in display's planar texture area. In the full color mode, meanwhile, the full color state is created in the focal conic texture area; and the dark color state is achieved in the cholesteric focal conic texture area. Either the absorptive circular polarizer or the reflective broadband circular polarizer can be used as the backside polarizer. A bright neutral white color with 50% front light reflection has been accomplished in the novel display.

BACKGROUND OF THE INVENTION

Cholesteric liquid crystal displays are characterized by the fact that the pictures stay on the display even if the driving voltage is disconnected. The bistability and multistability not only ensure a completely flicker-free static display but also have the

possibility of infinite multiplexing to create giant displays and / or ultra-high resolution displays. In cholesteric liquid crystals, the molecules are oriented in helices with a periodicity characteristic of material. In the planar state, the axis of this helix is perpendicular to the display plane. Light with a wavelength matching the pitch of the helix is reflected and the display appears bright. If an AC-voltage is applied, the structure of the liquid crystals changes from planar to focal conic texture. The focal conic state is predominately characterized by its highly diffused light scattering appearance caused by an abrupt change of the refractive indices at the boundary between cholesteric domains. This texture has no single optic axis. The focal conic texture is typically milky-white (i.e. white light scattering). Both planar texture and focal conic texture can coexist in the same panel or entity. This is a very important property for display applications, whereby the gray scale can be realized.

Current cholesterics displays are utilizing "Bragg reflection", one of the intrinsic properties of cholesterics. In Bragg reflection, only a portion of the incident light with the same handedness of circular polarization and also within the specific wave band can reflect back to the viewer, which generates a monochrome display. The remaining spectrum of the incoming light, however, including the 50% opposite handedness circular polarized and the out of Bragg reflection wave band, will pass through the display and be absorbed by the black coating material on the back surface of the display to ensure the contrast ratio. The overall light utilization efficiency is rather low and it is not qualified in some applications, such as a billboard at normal ambient lighting condition. The Bragg type reflection gives an impression that monochrome display is one of the distinctive properties of the ChLCD.

In many applications, human eyes are friendlier with full color spectrum, i.e. white color information written on the dark background. With the development of the flat panel display, more and more displays with neutral color have come into being, such as black-and-white STN display and AMTFT display, etc. Unfortunately, both of these approaches involve major disadvantages and limitations. The AMTFT displays are not true zero field image storage systems because they require constant power input for image refreshing. The STN displays do not possess inherent gray scale capability as a result of the extreme

steepness of the electro-optical response curve of the display. To realize a gray scale, the resolution has to be reduced by using, for example, four pixels instead of one per area. Anywhere from one to four pixels are activated at a particular time to provide the gray scale effect. The AMTFT devices use semiconductors to provide memory effects and involve the use of expensive, ultra high resistance liquid crystal materials to minimize RC losses. The cholesteric display has many advantages over the STN and AMTFT display with its zero field memory effect, hemispheric viewing angle, gray scale capability and other optical performances, but it obviously needs to come up with pure white reflection instead of the narrow band Bragg reflection to keep its superiority.

U.S.Pat. No. 5,493,430 introduces a way to attach a color plate to the back substrate of the display instead of a black one to achieve white on blue, white on yellow or "white on color" mode display. For example, a bluish white color appears on the planar texture pixels and the blue color appears on the focal conic texture pixels. The white color is derived from the pre-selected color of the Bragg reflection combined with the bluish background color. However the white color is only displayed in the normal angle and it exists a color shift when being viewed at an oblique angle. Furthermore, the display has a relatively low contrast ratio.

U.S.Pat. No. 5,796,454 introduces a black-and-white back-lit ChLC display. It includes controllable ChLC structure, the first circular polarizer laminating to the first substrate of the cell which has the same circular polarity as the liquid crystals, the second circular polarizer laminating to the second substrate of the cell which has a circular polarity opposite to the liquid crystals, and a light source. The display is preferably illuminated by a light source that produces natural "white" light. Thus, when the display is illuminated by the back light, the circular polarizer transmits the 50% component of the incident light that is right-circularly polarized. When the ChLC is in an ON state, the light reflected by the ChLC is that portion of the incident light having wavelengths within the intrinsic spectral bandwidth, and the same handedness; The light that is transmitted through the ChLC is the complement of the intrinsic color of ChLC. Since the transmitted light has right-circular polarization, it will be blocked by the left-circular polarizer. Therefore, this area will be substantially black. When the display is in an OFF state, the light transmitted through the polarizer is optically scattered by the ChLC in focal conic

structure. The portion of the incident light that is forward-scattered is emitted from the controllable ChLC structure as depolarized light. The left-circularly polarized portion of the forward-scattered light is then transmitted through the left-circular polarizer, and finally is perceived by an observer. Such black-and-white effect is achieved by the back-lit component and the ambient light is nothing but noise.

U.S.Pat. No. 6,344,887 introduces a method of manufacturing a full spectrum reflective cholesteric display, herein is incorporated by reference. '887 teaches a cholesteric display employing absorptive polarizers with the same polarity but different disposition. The display utilizes an absorptive circular polarizer and a metal reflector film positioned on the backside of the display to guide the second component of the incoming light back to the viewer. However, the shortcoming of the Iodine type absorptive polarizer makes the display to take on a tint of color in the optical ON state, for example, greenish white. The reasons for that are described as follows: Firstly, all the absorptive iodine polarizer has a more or less blue leaking problem which causes non-neutral color of a display device. Secondly, the absorptive polarizer has limited transmission (44%) and polarizing efficiency that causes the second reflection having less intensity than that of the first one. Thirdly, the metal reflector always has a limited reflectivity. Take the Aluminum for example, the reflectivity is in the range of 80~90%. Fourthly, the quarter waveform retardation film can only match a narrow wavelength of the light to generate a circularly polarized light. Addition to the multi-layer surface mismatching, the total reflection of the back absorptive circular polarizer is around 35%. All those reasons result in a full spectrum cholesteric display appearing non-paper white.

SUMMARY OF THE INVENTION

It is the primary objective of the present invention to realize a super white reflection in display's focal conic texture.

It is another objective of the present invention to create an optical dark state in display's planar texture.

It is still another objective of the present invention to use the Bragg reflection as the first color state.

It is also another objective of the present invention to use the complementary color of the Bragg reflection as the second color state.

It is again another objective of the present invention to take the advantage of the back scattering light of the focal conic texture to obtain the maximum brightness of the display.

It is furthermore another objective of the present invention to use a backside absorptive circular polarizer combined with a metal reflector.

It is still another objective of the present invention to utilize a specula reflective cholesteric polarizer to reflect the full spectrum incoming light in the focal conic texture and transmit most of the incoming light in the planar texture.

It is also another objective of the present invention to accomplish a neutral white front reflection over a hemispheric viewing angle.

It is again another objective of the present invention to create a reflective full color display by means of the micro color filter structure.

It is still another objective of the present invention to avoid using the Bragg reflection as an optical state.

It is furthermore another objective of the present invention to design a display cell structure with at least the front inner surface rubbed to generate a substantially single domain Bragg reflection, i.e., a mirror reflection.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 shows a schematic display structure of an absorptive circular polarizer, attached onto the back of the display cell, combined with a metal reflector.

FIG. 2 shows a schematic display structure of a specula reflective circular polarizer, attached onto the outside of the back substrate of the display cell, combined with a black painting layer.

FIG. 3 shows a schematic display structure of a specula reflective circular polarizer, attached onto the inside of the back substrate of the display cell, combined with an outside black painting layer.

FIG. 4 shows a schematic display structure of a front color filter deposited inside of the front substrate of the display cell.

FIG. 5 shows a schematic display structure of a back color filter deposited inside of the back substrate of the display cell.

DETAILED DESCRIPTION

Referring first to FIG. 1, illustrated is a front-lit color-and-white cholesteric display structure. A cell structure **100** includes a cholesteric liquid crystal material **110**, a front substrate **130** and a back substrate **140** and a polymeric ring material. The cell gap is controlled by a micro-beats with the diameter normally in the range of 2 ~ 6 μm, most preferably, 3μm. The front substrate and the back substrate are pre-coated a transparent thin film of conductive electrodes and a polyimide alignment layer on the inner surface, respectively. There are two cholesteric textures inside the cell structure: planar texture area **111** and focal conic texture area **112**. Both are electrically controllable. There is a special single domain design in the present invention. The front alignment layer **150** has been rubbed to generate a substantially single domain structure in the cholesteric planar area while the back alignment can be either rubbed or non-rubbed. It is well known that the single domain planar texture has a mirror Bragg reflection. The cell structure combined with a back absorptive circular polarizer **160** and a metal layer **170** to form a complete display panel. The back circular polarizer **160** is made of a linear absorptive polarizer and a quarter wave retarder at a 45-degree lamination. The retarder is physically attached to the back substrate **140** and the metal layer **170** is attached on the linear polarizer side. The handedness of the circular polarizer is designed to be the same as the helical structure of the cholesteric liquid crystal, for example, right-hand for the convenience of description.

When the natural light **180** reaches the cholesteric liquid crystal **110** in planar texture area **111** through the front substrate **130**, part of it (right-handed and within the Bragg wave band) will be mirror reflected (see light **181**). The rest of it, including left-handed component and the remaining right-handed portion (see light **182**) will hit on the back circular polarizer **160** through the area **111**. The left-handed circular polarizing light will

be filtrated by the right circular polarizer **160**. Only the remaining right-handed circular polarizing light **183** has a chance to be reflected by the metal reflector. One may notice that the light **183** is a complementary color of **181**. For example, if the Bragg reflection **181** is yellow, the light **183** will be blue. Furthermore, the light **183** passes the planer area **111**, and finally emerges to the display front surface as the right-handed circular polarization **184**.

There are two different appearances to the front viewer **120** in the display planar area depending on the emergent direction and distribution of the light **183**, which is determined by the pattern of the metal reflector **170**.

If the metal has a diffusive surface, it will reflect the light in a large distribution angle. The complementary color **183** will pass through the display cell and becomes a diffusive light **184**. Because the light **184** and light **181** have different emergent angle, the viewer can easily sense the lively saturate color **184** over a large viewing angle and sense the specula color **181** within a small viewing angle. In the present invention, two colors can be displayed in the same pixel depending on the viewing angle. In the normal ambient light condition, the light **184** is more preferable because of the viewing angle and the color density. As the light **181** has the same angle as the surface specula reflection, people always try to avoid this viewing direction subconsciously when they watch the display under the normal light condition. However, in the dark ambient light condition, the light **181** is valuable to the viewer. One of the two-color solution is that the color of light **181** is chosen as yellow and light **184** as deep blue. The other two-color solution is red for light **181** and greenish blue for light **184**.

If the metal has a specula surface, it will reflect the light in a narrow angle which is determined by the reflection law. The complementary color **183** will pass through the display cell and becomes a specula light **184**. Because the light **184** has the same emergent angle as the light **181** and the surface reflection, people always try to avoid this viewing direction subconsciously when they watch the display. So the display will take on a dark background over a large viewing angel in the planar area.

As the display addressed in a focal conic texture **112**, the display works in the optical white state. When the incident light **180** reaches the display cell with focal conic texture **112**, it will be scattered into milky-white color by the distribution of small, birefringence

domains. The light **180** will split into two portions, a substantial portion of the incident light (90 ~ 95%) being forward scattered **185** and the lesser portion (5 ~ 10%) being back scattered **188**. As the forward scattered light **185** hits on the composite structure of the back circular polarizer **160** and the reflector **170**, 50% right-handed polarized light **186** will be reflected back, while the other 50% left-handed light is absorbed by the circular polarizer **160**. The light **186** passes the display cell again and becomes depolarized light **187** due to the focal conic scattering effect. The emergent light **187** has a pure white color to the viewer. Moreover, the back-scattered light **188** in the focal conic texture area will directly reach to the viewer. The percentage of the back scattering to the total incoming light is depending on the cell thickness and the optical birefringence of the liquid crystal material.

Finally, there will be approximately 50% incoming light emergence from the display's focal conic area including the front scattered light **187** and back scattered light **188**. The brightness of the display is equal to that of the newspaper. What different from the prior art is that the present invention takes the advantage of back scattering as well as the forward scattering effect of the focal conic texture. In the prior art, the back scattering is always treated as a negative factor because it is harmful to the contrast of the display.

One of the fundamental differences of the present invention to the prior art is the neutral white performance. The present invention doesn't utilize planar texture as the white state and related color composition technologies. Furthermore, there is no polarizer or other optical component in front of the cell structure, which used to distort the whiteness of the emergence light.

The other fundamental difference of the present invention to the prior art is that the superior whiteness due to the addition of the back scattering effect. The novelty delivers a paper-white appearance with 50% reflectivity.

In order to enhance the contrast ratio, an optimal design of the liquid crystal formulation is necessary. Increasing the Δn, the optical birefringence of liquid crystals can both enhance the back scattering in the focal conic texture area and the complementary color in the planar texture area. Normally, the Δn needs to be in the range of 0.2 ~ 0.35, more preferably, 0.25 ~ 0.3.

Above all, with the bright white state in focal conic area and the dark color state in planar area, the present invention achieves a newspaper white display with a dark color.

Turning now to FIG. 2, illustrated is a schematical display structure, wherein a reflective circular polarizer, attached onto the outside of the back substrate of the display cell, combined with a black painting layer.

A cell structure **100** includes a cholesteric liquid crystal material **110**, a front substrate **130**, a back substrate **140** and a polymeric ring material. The cell gap is controlled by a micro-beats with the diameter normally in the range of 2 ~ 6 μm, most preferably, 3μm. The front substrate and the back substrate are pre-coated a transparent thin film of conductive electrodes and a polyimide alignment layer on the inner surface, respectively. There are two stable cholesteric textures inside the cell structure; planar texture area **111** and focal conic texture area **112**. Both are electrically controllable. There is a special single domain design in the present invention. The front alignment layer **150** has been rubbed to generate a substantially single domain structure in the cholesteric planar area while the back alignment can be either rubbed or non-rubbed. It is well known that the single domain planar texture has a mirror Bragg reflection. The display cell structure combined with a back reflective circular polarizer **260** and a black absorbing layer **270** to form a complete display panel. The back circular polarizer **260** is made of a cholesteric broadband polarizer. The handedness of the reflective circular polarizer is designed to be the same as the helical structure of the cholesteric liquid crystal, for example, right-hand for the convenience of description.

The working principle is almost the same as FIG.1. When the natural light **280** reaches the ChLC film **110** in planar texture area **111** through the front substrate **130**, part of it (right-handed and within the Bragg wave band) will be mirror reflected. The rest of it, including left-handed component and the remaining right-handed portion will hit on the reflective circular polarizer **260** through the area **111**. The left-handed circular polarizing light will then pass through the reflective circular polarizer **260** and finally absorbed by the black film. The right-handed circular polarizing light **283** is reflected by the polarizer **260**. One may notice that the light **283** is a complementary color of **281**. For example, if the Bragg reflection **281** is designed to be yellow, the light **283** will be blue.

Furthermore, the light **283** passes the planer area **111**, and finally emerges to the display front surface as the right-handed circular polarization **284**.

There are two different appearances to the front viewer **120** in the display planar area depending on the emergent direction and distribution of the light **283**, which is determined by the pattern of the reflective circular polarizer.

1. Diffusively reflective circular polarizer

If the reflective circular polarizer adopted is a diffusive one, it will reflect the light in a large distribution angle. The complementary color **283** will pass through the display cell and becomes a diffusive light **284**. Because the light **284** and light **281** have different emergent angle, the viewer can easily sense the lively saturate color **284**. Since the light **281** has the same angle as the surface specula reflection, people always try to avoid this viewing direction subconsciously when they watch the display. If the color of light **281** is chosen as yellow, the **284** will be deep blue.

2. Specula reflective circular polarizer

If the polarizer adopted is a specula circular polarizer it, will reflect the light in a narrow angle which is determined by the reflection law. The complementary color **283** will pass through the display cell and becomes a specula light **284**. Because the light **284** has the same emergent angle as the light **281** and as the surface reflection, people always try to avoid this direction subconsciously when they watch the display. So the display will take on a dark background over a large viewing angel in the planar area.

As the display addressed in a focal conic texture **112**, the display works in the optical ON state. When the incident light **280** reaches the display cell with focal conic texture **112,** it will be scattered into milky-white color. The light **280** will split into two portions, a substantial portion of the incident light (90 ~ 95%) being forward scattered **285** and the lesser portion (5 ~ 10%) being back scattered **288**. As the forward scattered light **285** hits on the reflective circular polarizer **260**, the portion of the right-handed polarized light **286** will be reflected back, while the portion of the left-handed light will be absorbed by the black layer **270**. The light **186** passes the display cell again and becomes depolarized light **287** due to the focal conic scattering effect. The emergent light **287** has a pure white color to the viewer. Moreover, the back-scattered light **288** in the focal conic texture area

will directly reach to the viewer. The percentage of the back scattering is depending on the cell thickness and the optical birefringence of the liquid crystal material.

Finally, there will be over 50% incoming light emergence from the display's focal conic area, including the front scattered light **287** and back scattered light **288**. The brightness of the white state is equal to or better than that of the newspaper. What different from the prior art is that the present invention takes the advantage of back scattering as well as the forward scattering effect in the focal conic texture. In the prior art, the back scattering is always a negative factor and being thought harmful to the contrast of the display.

Above all, with the bright white state in focal conic area and the dark color state in planar area, the present invention achieves a paper white display on a dark background.

Turning now to FIG.3, illustrated is a schematical display structure, wherein a reflective circular polarizer, attached onto the inside of the back substrate of a display cell, combined with a outside black painting layer.

The manufacture of the back substrate is described as follows. Firstly, the inside surface of the glass panel **340** is coated by a UV curable cholesteric material with the thickness of 20μm which is polymerized under a suitable condition and duration. Secondly, an over coating (OC) material is spin-coated on the top of the broadband cholesteric layer with the thickness of 17μm and is thermo-cured completely. Fourthly, an ITO transparent conductive layer is sputtered on the top of the OC layer with the thickness of 0.18μm. Finally, a chemical wet imaging process is carried out. A black coating layer or an equivalent back housing structure **370** is attached on the back of the substrate.

The working principle is almost the same as FIG.2. When the natural light **380** reaches the cholesteric film **110** in planar texture area **111** through the front substrate **130**, part of it (right-handed and within the Bragg wave band) will be mirror reflected. The rest of it, including left-handed component and the remaining right-handed portion will hit on the reflective circular polarizer **360** through the area **111**. The left-handed circular polarizing light will then pass through the reflective circular polarizer **360** and finally absorbed by the black film. The right-handed circular polarizing light which is reflected

by the polarizer **360** passes the planer area **111** and finally emerges to the display front surface as the right-handed circular polarization **384**.

There are two different appearances to the front viewer **120** in the display planar area depending on the emergent direction and distribution of the light **184**, which is determined by the pattern of the reflective circular polarizer.

1. Diffusively reflective circular polarizer

   If the reflective circular polarizer adopted is a diffusive one, it will reflect the light in a large distribution angle. The complementary color **383** will pass through the display cell and becomes a diffusive light **384**. Because the light **384** and light **381** have different emergent angle, the viewer can easily sense the lively saturate color **384**. Since the light **381** has the same angle as the surface specula reflection, people always try to avoid this viewing direction subconsciously when they watch the display. If the color of light **381** is chosen as yellow, the **384** will be deep blue.

2. Specula reflective circular polarizer

   If the polarizer adopted is a specula circular polarizer, it will reflect the light in a narrow angle which is determined by the reflection law. The complementary color **383** will pass through the display cell and becomes a specula light **384**. Because the light **384** has the same emergent angle as the light **381** and as the surface reflection, people always try to avoid this direction subconsciously when they watch the display. So the display will take on a dark background over a large viewing angel in the planar area.

As the display addressed in a focal conic texture **112**, the display works in the optical ON state. When the incident light **380** reaches the display cell with focal conic texture **112**, it will be scattered into milky-white color by a distribution of small, birefringence domains. The light **380** will split into two portions, a substantial portion of the incident light (90 ~ 95%) being forward scattered and the lesser portion (5 ~ 10%) being back scattered **388**. As the forward scattered light hits on the reflective circular polarizer **360**, the portion of the right-handed polarized light will be reflected back, while the portion of the left-handed light will be absorbed by the black layer **370**. The reflected light passes the display cell again and becomes depolarized light **387** due to the focal conic scattering effect. The emergent light **387** has a pure white color to the viewer. Moreover, the back-

scattered light **388** in the focal conic texture area will directly reach to the viewer. The percentage of the back scattering is depending on the cell thickness and the optical birefringence of the liquid crystal material.

Finally, there will be over 50% incoming light emergence from the display's focal conic area, including the front scattered light **387** and back scattered light **388**. The brightness of the display ON state is better than that of the newspaper. What is different from the prior art is that the present invention takes the advantage of back scattering effect as well as the forward scattering effect in the focal conic texture. In the prior art, however, the back scattering is always a negative factor and harmful to the contrast of the display.

One of the fundamental differences of the present invention to the prior art is the neutral white performance. The present invention doesn't utilize the planar texture as the white state and related color composition technologies. Furthermore, there is no polarizer or other optical component being positioned in front of the cell structure that jeopardizes the transmission of the emergence light.

The other fundamental difference of those state of the art to the prior art is that the superior whiteness due to the addition of the back scattering effect. The present invention delivers a paper-white appearance with 50% reflectivity.

Above all, with the white state in focal conic area and the dark color state in planar area, the present invention achieves a paper white display on the dark background.

Turning now to FIG.4, illustrated is a front color filter positioned inside of the display cell.

A color filter layer **490**, including red, green and blue patterning, is deposited on the front substrate **430**. The Bragg reflection out of **110** will be substantially cut off by the front color filter **490**, due to the fact that the wave band of the Bragg reflection is designed on purpose in non-primary color band, for example, yellow color with the wavelength of 580nm.

When the natural light **480** passes through the front color filter layer **490**, it will be attenuated initially by the absorptive coloring material. The remaining portion will then reach the cholesteric film **110** in planar texture area **111**, part of it (right-handed and

within the Bragg wave band), light **481** will be mirror reflected and further absorbed by the color filter structure. The rest of it, including left-handed component and the remaining right-handed portion will hit on the reflective circular polarizer **260** through the area **111**. The left-handed circular polarizing light **482** will then pass through the reflective circular polarizer **260** and finally be absorbed by the black film, while the right-handed circular polarizing light **483** will be reflected by the polarizer **260**. One may notice that the light **483** is a complementary color of **181**. For example, if the Bragg reflection **481** is designed to be yellow, the light **483** will be blue. Furthermore, the light **483** passes the planer area **111**, and once more being absorbed by the front color filter layer and finally emerges to the display front surface as the right-handed circular polarization **484**. Due to the multi-path absorptions, the light **484** is only a small percentage of the incoming light and it takes on a black dark with a little color tint.

As the display addressed in a focal conic texture **112**, the display works in the full color state. When the portion of the incident light **480** reaches the display cell with focal conic texture **112** through the color filter layer where a portion of the light **480** being attenuated, the remaining light will be scattered into milky-white color by a distribution of small, birefringence domains. The remaining light will split into two parts, a substantial portion of the incident light (90 ~ 95%) being forward scattered **485** and the lesser portion (5 ~ 10%) being back scattered (see light **488**). As the forward scattered light **485** hits on the reflective circular polarizer **260**, the portion of the right-handed polarized light will be reflected, while the portion of the left-handed light **486** will be absorbed by the black layer **270**. The light passes the display cell again and becomes depolarized light due to the focal conic scattering effect. The emergent light **487** and **488** are colored light which is predetermined by the color filter.

Above all, with the full color state in focal conic area and the dark state in planar area, the present invention achieves a full color reflective display.

Turning now to FIG.5 illustrated is a sectional drawing of a display structure, wherein a color filter layer is positioned on the back substrate of a display cell structure.

The working principle is almost the same as FIG.4. When the natural light **580** reaches the cholesteric film **110** in planar texture area **111** through the front substrate **130**,

part of it (right-handed and within the Bragg wave band) will be mirror reflected (see light **581**). The rest of it, including left-handed component and the remaining right-handed portion will pass through the internal color filter layer **590** where being partially attenuated. The remaining portion of the light will hit on the reflective circular polarizer **260** through the area **111**. The left-handed remaining light will then pass through the reflective circular polarizer **260** and finally be absorbed by the black film **270**. The right-handed circular polarizing light **583** reflected by the polarizer **260** passes the planer area **111** and finally emerges to the display front surface as the right-handed circular polarization **584**.

There are two different appearances to the front viewer **120** in the display planar area depending on the emergent direction and distribution of the light **584** which is determined by the pattern of the reflective circular polarizer.

The specula reflective circular polarizer adopted will reflect the light in a narrow angle which is determined by the reflection law. The complementary color **583** will pass through the display cell and becomes a specula light **584**. Because the light **584** has the same emergent angle as the light **581** and as the surface reflection, people always try to avoid this direction subconsciously when they watch the display. So the display will take on a dark background over a large viewing angel in the planar area.

As the display addressed in a focal conic texture **112**, the display works in the full color state. When the incident light **580** reaches the display cell with focal conic texture **112**, it will be scattered into milky-white color by a distribution of small, birefringence domains. The light **580** will split into two portions, a substantial portion of the incident light (90 ~ 95%) being forward scattered and the lesser portion (5 ~ 10%) being back scattered **588**. As the forward scattered light passing through the color filter layer, it will be selectively absorbed by the color filter array. The remaining light will then hit on the reflective circular polarizer **260**, the portion of the right-handed polarized light will be reflected, while the portion of the left-handed light will be absorbed by the black layer **270**. The reflected light passes the color filter as well as the display cell again and becomes colored depolarized light due to the focal conic scattering effect. The emergent light **587** has a color or a color reproduction to the viewer. One may notice that, the back-scattered light **588** in the focal conic texture area will directly reach the viewer. The

percentage of the back scattering is depending on the cell thickness and the optical birefringence of the liquid crystal material.

Above all, with the full color state in focal conic area and the dark state in planar area, the present invention achieves a full color reflective display with a dark color. The advantage of this display structure is the white color brightness. Compared with the FIG.4, the display looks whiter and brighter but the full color image will be dilute by the back scattering to a certain extent. Whiteness is indeed an important parameter of the reflective display. However, in case of the color purity or color saturation is required, the front color filter structure as depicted in FIG. 4 is preferred.